

Corrosion Mitigation Strategies - an Introduction

US Army Corrosion Summit

February 5, 2009

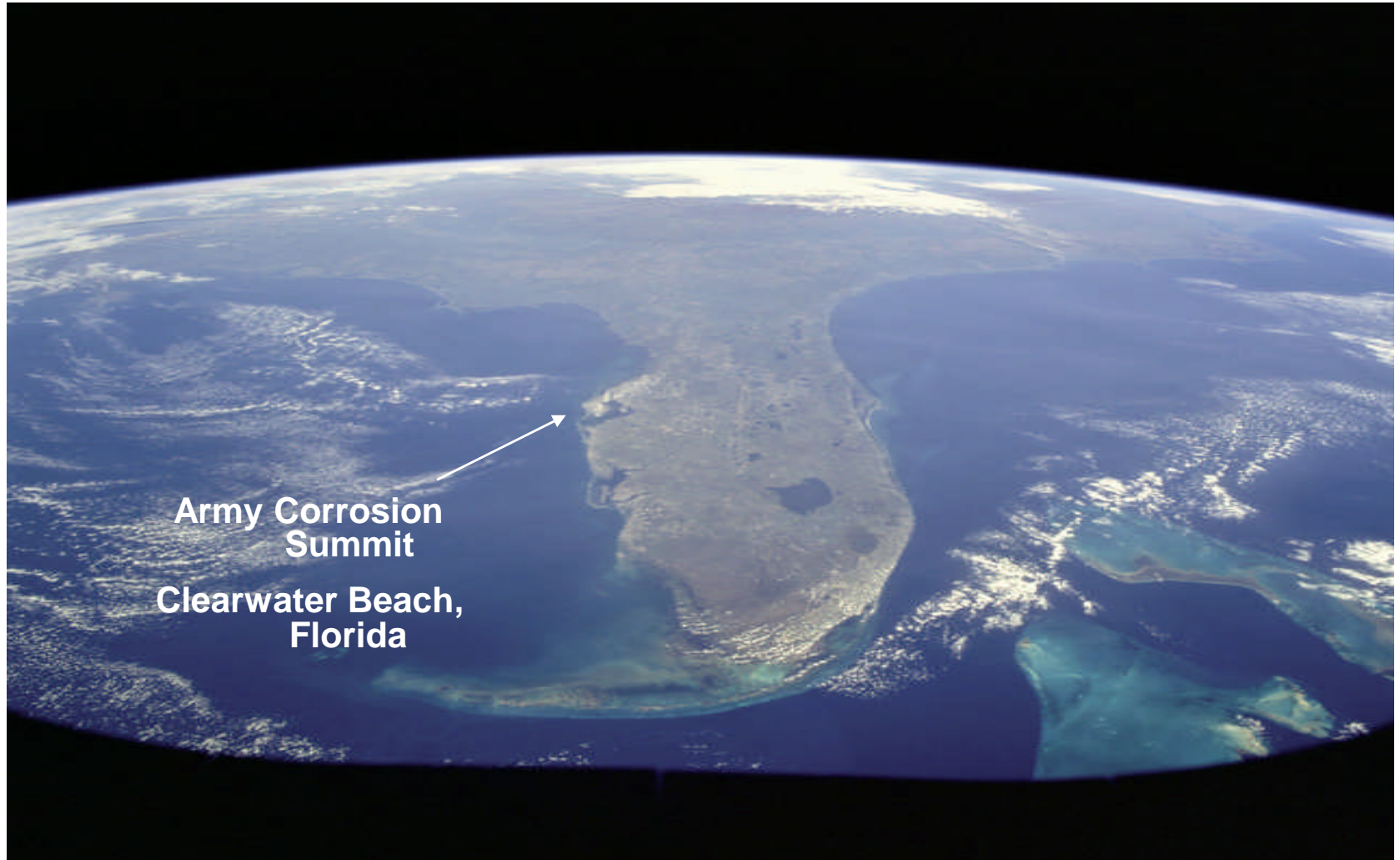
Joe Curran



Leaders in Corrosion Control Technology

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Where Are We?



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Corrosion Mitigation Strategies

- Experience
- Design
- Materials Selection
- Protective Coatings
- Cathodic Protection
- Modification of Environment

Experience

- Similar applications
 - Previous successes
 - Previous failures
- Material performance data
- Selection based on testing
- Corrosion Engineer on the design team

Design

- Materials Selection
- Process Parameters
- Construction Parameters
- Geometry for Drainage
- Dissimilar Metals
- Operating Lifetime
- Maintenance and Inspection
- Crevices
- Corrosion Allowance

Design – Process Parameters

- Temperature
- Velocity
- Pressure
- Chemistry

Design – Temperature

- Direct and indirect effects
 - Rates of diffusion-solubility of gases
 - Affects the surrounding service environment
- Nominal operating
 - Significant effects if varied from normal

Design – Temperature

- Maximum operating/upset
 - Surface deposit formation (heat zones)
 - Affects stable protective films
- Minimum operating
 - Condensable gasses deposited on surfaces
- Downtime

Design – Velocity

- Flow rates
 - Fast/slow/stagnant
 - High rates are severe
 - Impingement by entrained solids
 - Availability of corrosion elements
 - Removal of protective films
- Cavitation

Design – Velocity

- Flow regime
 - System
 - Bi-directional
 - Treatments
 - Methods

Design – Pressure

- Total hydraulic pressure
 - Affects the types of corrosion products formed
 - Stress corrosion cracking
- Overpressure
 - Pressure of a gas over a liquid-solubility of gases in the liquid
- O

Design – Pressure

- Pressure variations
 - Length-pressure drop
 - Reducers
 - Expanders
 - Elbows
 - Power surges
 - Crack protective films, fretting, fatigue

Design – Chemistry

- Used to eliminate candidate materials
- pH acidic (H^+) basic (OH^-) neutral
- Ionic concentrations
 - Major species affect the passive film
 - Minor species in localized attack
- Nature of environment

Design – Construction Parameters

- Shop vs field
- Welding
 - Heat affected zone
- Accommodating for additional corrosion control measures

Methods of Corrosion Control–Design

Dissimilar Metals Considerations

- Potential differences
- Area ratio
- Control by:
 - Compatible materials
 - Area ratio control
 - Insulation
 - Coatings

Methods of Corrosion Control–Design

Corrosion Allowance

- Anticipated lifecycle of asset
- Allow for corrosion to occur
 - Add extra material
 - Uniform attack
 - Linear or decreasing rate

Methods of Corrosion Control–Design

Inspection/Maintenance

- Maintenance manuals
- Ease of access

Methods of Corrosion Control–Materials Selection

- Corrosion resistance in environment
- Availability of data
- Mechanical properties
- Cost
- Availability
- Maintainability
- Compatibility
- Life expectancy
- Reliability
- Appearance



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Methods of Corrosion Control–Materials Selection

Environment

- Main constituents
- Impurities
- Temperature
- pH
- Degree of aeration
- Velocity or agitation
- Pressure
- Range of each variable



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Methods of Corrosion Control–Materials Selection

Test Data

- Specific service environment
- Actual service - identical service
- Actual service - similar environment
- Laboratory tests
- Published data

Methods of Corrosion Control–Materials Selection

Mechanical Properties

- Strength
- Ductility
- Environmental cracking
 - Hydrogen evolution
 - Stress corrosion cracking
 - Corrosion fatigue

Methods of Corrosion Control–Materials Selection

Cost

- Economic analysis
- Fabrication costs
- Other costs
 - Maintenance
 - Repair

Methods of Corrosion Control–Materials Selection

Cost

- Maintenance costs
- Unscheduled shutdowns
- Safety
- Other costs
 - Environmental damage
 - Product contamination

Methods of Corrosion Control–Materials Selection

Compatibility

- Consider entire system
 - Components can interact
- Galvanic effects
 - Cathodic/anodic ratio
- Metal ion effects
 - Fe/Cu Cu/Al Hg/Al

Methods of Corrosion Control–Materials Selection

Life Expectancy

- Inspection and maintenance guidelines
- Establishing life requirement
- Short life - frequent replacement

Methods of Corrosion Control–Materials Selection

Reliability

- Safety often an issue
 - Accidents, product contamination
 - Corrective corrosion control inappropriate
- Reliability often outweighs cost

Methods of Corrosion Control–Materials Selection

Comparison with Other Methods

- Materials selection important
- Additional methods
 - Coatings
 - Cathodic protection
 - Corrosion inhibitors
 - Combination of methods
- Balance cost and other factors

Methods of Corrosion Control–Materials Selection

Candidate Materials - Metals

- Metallurgy
- Carbon and low-alloy steels
- Stainless steels
- Nickel and nickel-based alloys
- Copper and copper alloys
- Aluminum and aluminum alloys
- Titanium and titanium alloys

Methods of Corrosion Control–Materials Selection

Nonmetals

- Plastics-UV light, heat, solvents
- Composites-environmental attack
- Elastomers-UV, ozone, solvents, oxygen
- Concrete-acids, chlorides, sulfates
- Vitreous Materials-solvents

Methods of Corrosion Control–Protective Coatings

- Corrosion Control
- Waterproofing
- Weather protection
- Biocide
- Fireproofing
- Appearance
- Color coding
- Sanitation/decontamination
- Safety
- Prevent contamination
- Friction reduction
- Wear resistance
- Heat transfer
- Electrical insulation
- Sound deadening

Methods of Corrosion Control –Protective Coatings

- Organic coatings
 - Barrier
 - Inhibitive pigments
 - Cathodic protection

Methods of Corrosion Control –Protective Coatings

- Chemical resistance
- Low permeability
- Easy to apply
- Adhesion
- Cohesive strength
- Tensile strength
- Flexibility/ elongation
- Impact resistance
- Abrasion resistance
- Temperature resistance
- Cold flow resistance
- Dielectric strength
- Cathodic disbondment resistance

Methods of Corrosion Control–Protective Coatings

Selection

- Type of exposure
- Operating/upset conditions
- Substrate
- Application conditions
- Environmental regulations
- Cost
- Application - operation/shutdown
- Time constraints
- New construction/maintenance
- Shop/field application
- Design/fabrication

Methods of Corrosion Control –Protective Coatings

Design Defects

- Inaccessible areas
- Fasteners
- Gaps
- Angles
- Threaded areas
- Dissimilar metals

Methods of Corrosion Control –Protective Coatings

Fabrication Defects

- Imperfect welds
- Weld splatter
- Skip welds
- Rough welds
- Laminations
- Gouges
- Sharp corners

Coating Failures

What causes the majority of coating failures?

Poor Surface Preparation

- Rust
- Mill scale
- Anchor pattern
- Residues
 - Oil/grease/soil
 - Chemicals
- Ridges/burrs/sharp edges
- Moisture
- Old Coatings

Surface Preparation – Standards

- NACE
- ISO
- SSPC

Methods of Corrosion Control –Protective Coatings

Coating Application

- Manual
 - Brush
 - Roller
 - Palming
- Spray
 - Conventional air
 - Airless
 - Electrostatic
 - Thermal spray

Methods of Corrosion Control

Coating Application

- Production Techniques
 - Hot dipping
 - Fluidized bed
 - Powder spray

Methods of Corrosion Control

Protective Coating - Inspection

- Surface preparation
 - Cleanliness
 - Anchor profile
- During application
 - Verify conditions
 - Application technique
 - Wet film thickness
- Post application
 - Dry film thickness
 - Adhesion
 - Holidays

Methods of Corrosion Control–Protective Coatings

- Wraps and tapes
- Insulation
- Metallic coatings
 - Coating anodic to base metal
 - Coating cathodic to base metal

Methods of Corrosion Control–Protective Coatings

- External Pipeline Coatings
 - Fusion Bonded Epoxy (FBE)
 - Extruded thermoplastic
 - Coal Tar Enamel
 - Tape
 - Concrete (Weight) Coating

Methods of Corrosion Control – Electrochemical Techniques

- Make metal to be protected act as a cathode
- Application of electrical current
- From corroding anode (galvanic)
- From external power source (impressed)

Methods of Corrosion Control – Cathodic Protection–Galvanic

- Anode requirements
 - Potential
 - Long Life
 - Efficiency
- Aluminum
- Magnesium
- Zinc
 - Fresh water vs salt water

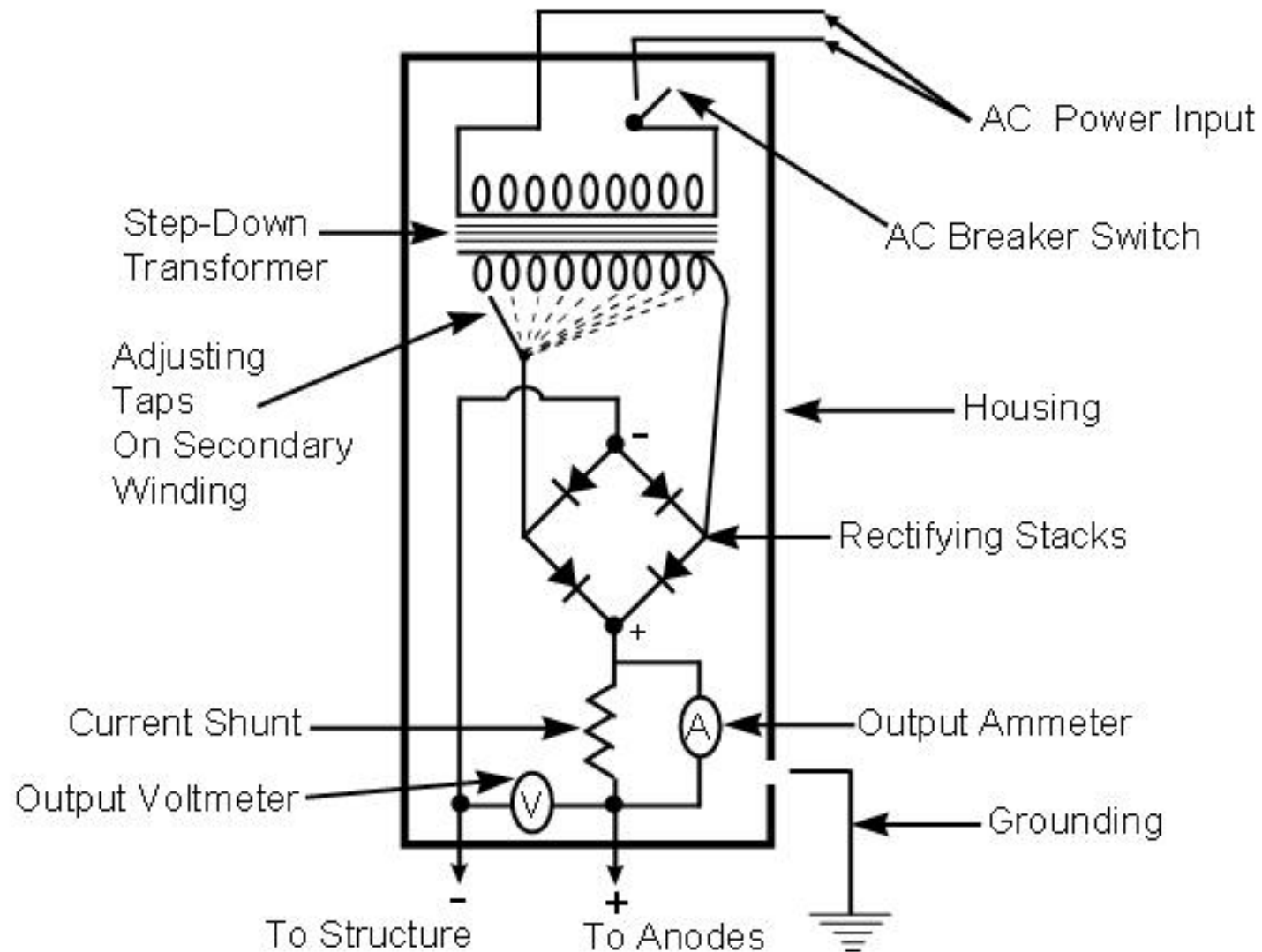
Methods of Corrosion Control – Cathodic Protection–Impressed

- External current source
- Ground bed required
 - Anode consumption not required
 - Inert (low consumption rate) anodes

Methods of Corrosion Control – Cathodic Protection–Impressed

- **Caution!** - *Positive terminal of rectifier always connected to ground bed*
- Anodes
 - Scrap iron
 - Silicon cast iron
 - Graphite
 - Magnetite
 - Lead-silver
 - Platinum

Transformer-Rectifier Schematic



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Methods of Corrosion Control – Cathodic Protection–Impressed

- **Caution!** - *Positive terminal of rectifier always connected to ground bed*
- Power sources
 - Rectifiers
 - Solar cells
 - Generators
 - Wind
 - Thermoelectric

Methods of Corrosion Control – Cathodic Protection–Measurement

- Structure- to-electrolyte potential
 - Reference electrode
- Test coupons
- Potential change

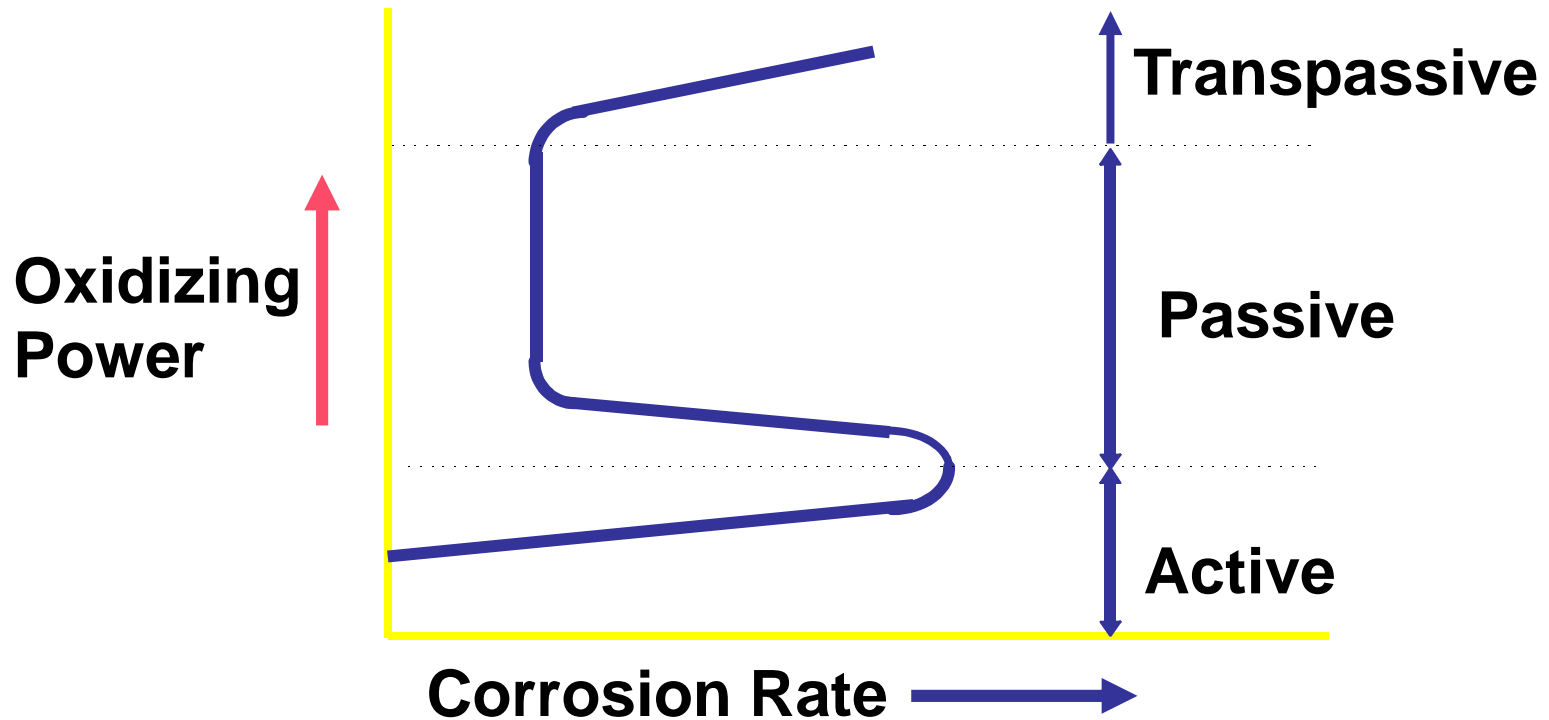
Methods of Corrosion Control – Cathodic Protection–Design

- Regulations Wire & cable
- Anode backfill Temperature
- Coatings Current Environment
- Shielding Stray currents
- Economics Metal
- Life

Methods of Corrosion Control – Cathodic Protection–Maintenance

- Galvanic
 - Anode consumption/replacement
 - Wire damage
- Impressed current
 - Power source
 - Ground bed connection

Methods of Corrosion Control – Anodic Protection



Methods of Corrosion Control – Modification of Environment

- Augment inherent corrosion resistance
 - Corrosion inhibitors
 - Deaeration
 - pH control

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors

- Film Formation
 - Adsorption
 - Bulky precipitates
 - Passive films

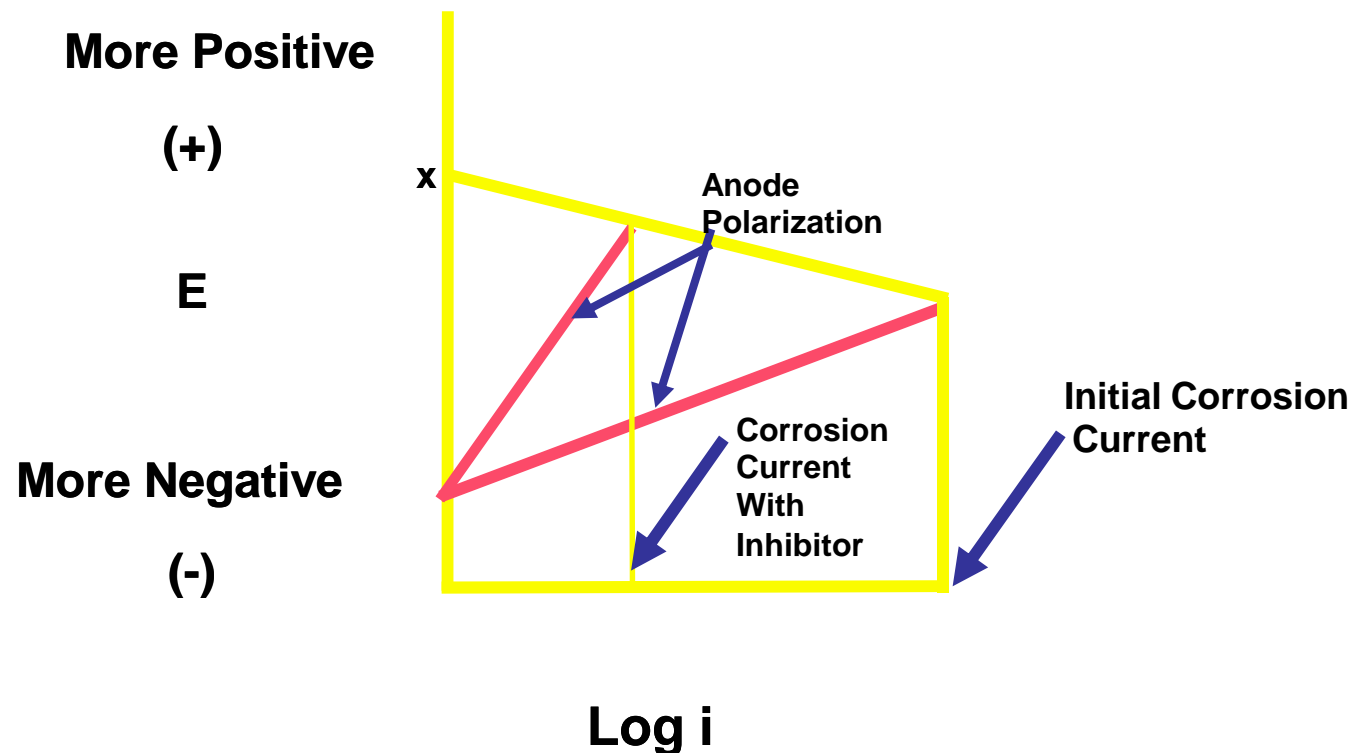
Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors

- Types of Inhibitors
 - Passive (anodic)
 - Cathodic
 - Ohmic
 - Precipitation-inducing
 - Vapor phase

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Anodic)



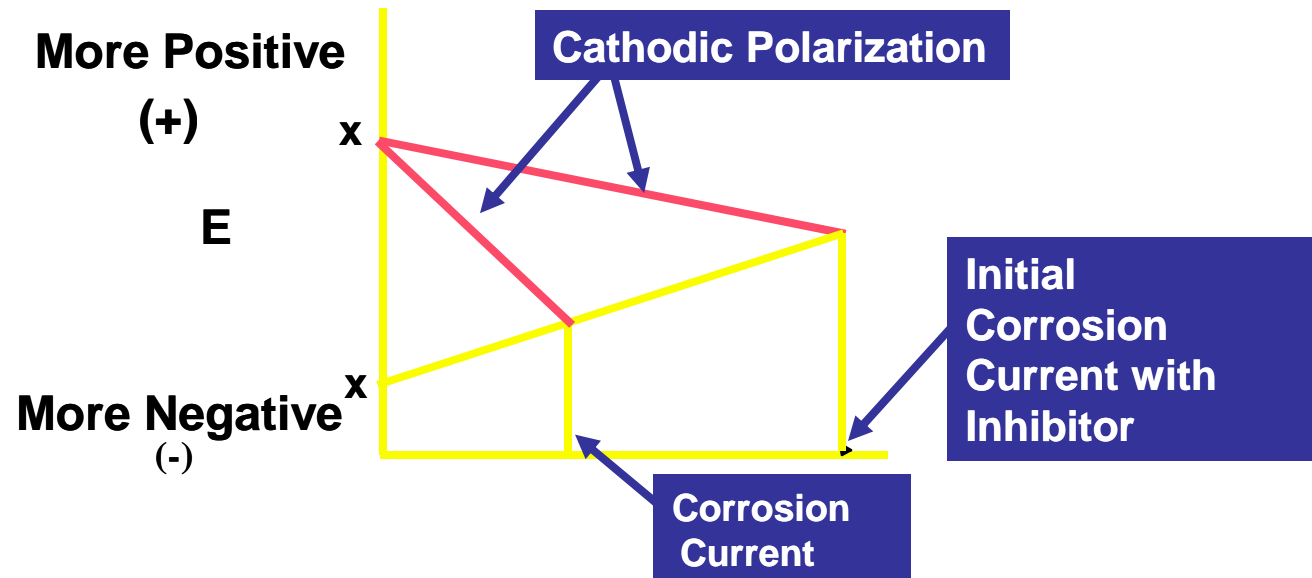
Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Anodic)

- Can cause accelerated local attack if used in insufficient amounts
- Oxidizing
- Non-oxidizing

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Cathodic)



Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors Passivating (Cathodic)

- Cathodic poisons
 - Inhibit cathodic reactions
 - Inhibit hydrogen formation/ evolution
 - Hydrogen damage
- Cathodic precipitates
 - Increased pH at cathode

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Ohmic

- Increase resistance
- Resistive film
 - Anodic areas
 - Cathodic areas
 - Entire surface

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Organic

- Can film entire surface
- Cationic (+)
- Anionic (–)

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Precipitation

- Film-forming compounds
- Can film entire surface
- May act as anodic inhibitors
 - With oxygen
 - Local attack if insufficient amount

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Vapor Phase

- Closed systems
- Volatile solids
- Volatile liquids
- Alkaline films
- Hydrophobic films
- May accelerate attack of some metals

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Aqueous liquid systems
- Affected by environment
 - Oxygen
 - Hydrogen ions
 - Temperature
 - Sulfate
 - Metal cations
 - Hydroxyl ions
 - Chloride
 - Bicarbonate

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Nonaqueous liquid systems
 - Fuels
 - Lubricants
 - Edible oils
- Water content
- Acids

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application

- Gaseous environments
- Open atmosphere
- Vapor phase in tanks
- Natural gas production
- Packaging containers

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Application Techniques

- Continuous injection
- Batch treatment
- Squeeze treatment
- Coatings

Methods of Corrosion Control – Modification of Environment

Corrosion Inhibitors - Safety

- Handling
- Disposal

Corrosion Inhibitors - Heat Transfer

Methods of Corrosion Control – Modification of Environment

Water Treatment

- Physical
 - Removal of solids
 - Removal of liquids
 - Removal of gasses
- Chemical
 - Softening
 - pH adjustment
 - Demineralization
 - Desalination
 - Oxygen scavenging

Methods of Corrosion Control –Summary

- Design
- Materials Selection
- Protective Coatings
- Cathodic Protection
- Modification of Environment